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The Anatomy of Growth in the OECD since 1870: the Transformation from the Post-Malthusian Growth Regime to the Modern Growth Epoch¹

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Abstract.

This paper extends conventional growth accounting exercises to allow for endogeneity of capital, the demographic transition, age dependency, and employment rates among other factors. Using data for the OECD countries in the period 1870-2006 it is shown that growth has been predominantly driven by demographics and TFP growth. TFP has in turn been driven by R&D, knowledge spillovers through the channel of imports, educational attainment, and the interaction between educational attainment and the distance to the frontier. The estimates suggest permanent growth effects of R&D and human capital and, therefore, that growth can be expected to be positive for the rest of this century.

JEL Classification: O30, O40

Key words: human capital, demographic transition, endogenous growth models

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1 Introduction

The Second Industrial Revolution in the late 19th century marked a watershed in human history by transforming the Western European countries and their offsprings from a post-Malthusian low-growth regime to a modern economic growth regime (Galor, 2005). However, the forces which have been responsible for income growth in the OECD countries since 1870 remains a mystery. Using growth accounting methods Solow (1957), Denison (1962) and Jorgenson *et al.* (1987) find that per capita growth in the US in the first half of the 20th century was predominantly driven by growth in TFP and capital deepening. Denison (1962) found that factor accumulation and improved quality of inputs accounted for 73% of productivity growth while TFP accounted only for 27% of productivity growth in the period 1909-1957. Similarly, Jorgenson *et al.* (1987) conclude that “growth in capital input is the most important source of growth in value added, growth in labor input is the next important source, and productivity growth is the least important,” (p 21-21).³

While growth accounting gives insight into capital accumulation during the transitional path from one steady state to another, it does not reveal which factors have been responsible for the growth in TFP and, more seriously, it attributes excessive weight to capital deepening as it fails to allow for TFP-induced capital deepening (Klenow and Rodriguez-Clare, 1997, Barro and Sala-i-Martin, 2004). Since per capita income growth equals TFP growth along the balanced growth path in modern growth models growth accounting only sheds light on sources of growth to the extent that productivity growth is driven predominantly by transitional dynamics. Furthermore, Rebelo and King (1993) demonstrate that the Solow model’s transitional dynamics cannot account for sustained growth. If the productivity growth rates have been predominantly due to transitional dynamics implausibly high initial interest rates or implausibly low consumption shares would have been required to generate the growth rates that the OECD countries have experienced since the Second Industrial Revolution. Neither stock returns nor consumption rates have changed much over the past century (Madsen and Davis, 2006, Rebelo and King, 1993). Nelson (1973) is even more critical by noting that growth accounting exercises “have run into sharply diminishing returns and soon will arrive at a dead end” (p 462).

These considerations suggest that an alternative to the standard growth accounting exercise is called for. The empirical estimates of Dowrick and Nguyen (1989), Dowrick and Gemmell (1991), Coe and Helpman (1995), Lichtenberg and Van Pottelsberghe de la Potterie (1998), Vamvakidis (2002), Zachariadis (2004), Ha and Howitt (2007) and Madsen (2007, 2008a, 2008b) show that knowledge spillovers and innovative activity have been important contributors to

³ Solow (1957) finds that only one eighth of US growth over the period from 1909 to 1949 was due to capital deepening. The importance of capital for growth diminishes when the period is extended and when a more detailed account for the quantity and the quality of factors of production is considered (Denison, 1962, Jorgenson *et al.*, 1987).

productivity growth in the OECD countries. There are, however, two reasons as to why modern endogenous growth models cannot explain all productivity growth over the past 137 years. First, per capita growth cannot simply have been driven by TFP along a balanced growth path. Transitional dynamics must have played a role for growth since 1870 given that age dependency rates, educational attainment, labor force participation rates, the capital-output ratio, and annual hours worked have changed substantially since then. As shown below the OECD countries have been outside their balanced growth path initially and for prolonged periods to such an extent, that transitional dynamics have been important for growth.

Second, modern growth theories are derived under the assumption that capital and labor/human capital are the only factors of production, which implies that labor productivity growth equals TFP growth in steady state. While this assumption is a useful approximation for the OECD countries in post-1970 period it cannot strictly be maintained before then; particularly not before WWII, and for most developing countries. In 1870 agriculture accounted for 36 percent of production on average for the 17 countries considered in this paper, henceforth referred to as the G17. Consequently, the omission of land as a factor of production will lead to biased estimates. If land is a factor of production and the CRTS assumption for land, capital and labor is maintained, the one-to-one mapping between growth in TFP and labor productivity along the balanced growth path, breaks down. Population growth creates a wedge between growth in TFP and growth in labor productivity along the balanced growth path because of the diminishing returns introduced by land as a fixed factor of production.

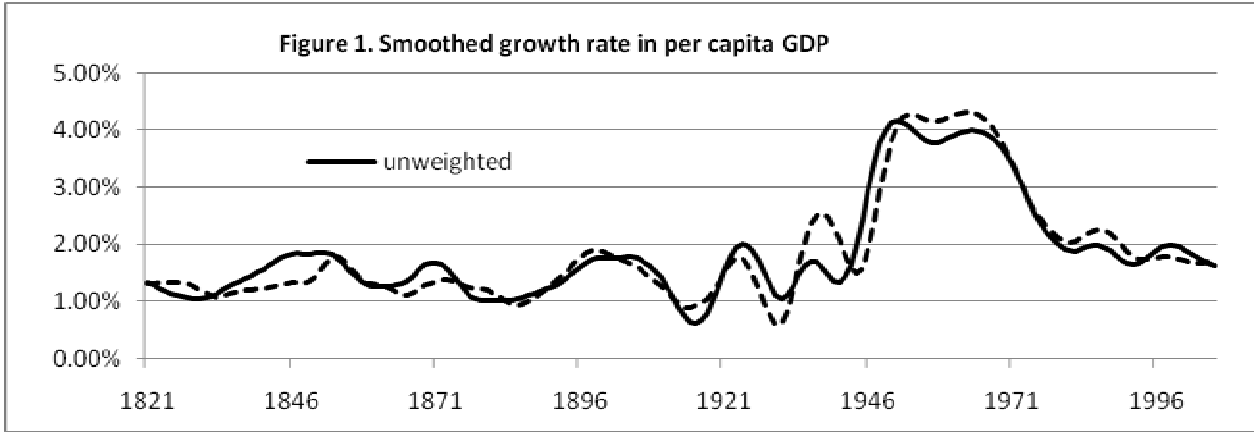
A further complication is that it is not clear which endogenous growth theory best explains TFP growth and the role played by international knowledge spillovers. In the first-generation endogenous growth models of Lucas (1988), Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992) growth is driven by the economy-wide stock of human capital and R&D. Following Jones' (1995) critique the stock effects have been abandoned in the second-generation endogenous growth models. The Schumpeterian models of Aghion and Howitt (1998), Peretti (1998), Howitt (1999), Howitt (2000), Peretti and Smulders (2002), and Aghion, Boustan, Hoxby, Vadenbussche (2005), maintain scale effects from first-generation endogenous growth models but assume that the effectiveness of R&D dilutes, due to the proliferation of products as the economy expands. The semi-endogenous growth model of Jones (1995, 2002) abandons scale-effects in ideas production and consequently R&D and human capital have no level effects. Shocks to R&D and human capital have only transitory effects. While Ha and Howitt (2007) and Madsen (2008a) find that Schumpeterian models are more consistent with the evidence than semi-endogenous growth models they limit their empirical estimates to R&D and patents and, as such, omit the influence of educational attainment on growth.

This paper seeks to explain the factors that have been responsible for growth in the OECD countries since the Second Industrial Revolution by combining growth accounting methods, unified theories of economic growth, and endogenous growth theories. Growth accounting methods are extended to allow for the demographic transition following unified theories of economic growth (see for example Galor, 2005) and endogeneity of capital deepening following Jones (2002). The extended growth accounting method is used to pinpoint the contribution to per capita growth of changing labor force participation rates, changing capital-output ratios, changing age dependency ratios, and change in the annual hours worked. Based on recent developments in endogenous growth theory the contribution of TFP productivity growth is explained by innovative activity, educational attainment, distance to the frontier, and the interaction between educational attainment and distance to the frontier, and knowledge spillovers through the channel of imports.

The estimates are based on a new data set for 17 OECD countries covering the period from 1870 to 2006. Section 2 establishes the analytical framework. Section 3 decomposes sources of productivity growth based on endogenous growth accounting. The effects on labor productivity and TFP growth of the innovative activity, human capital, and knowledge spillovers and the interaction between educational attainment and the distance to the frontier are estimated in Section 4. Section 5 simulates the factors that have accounted for TFP and labor productivity growth since 1870 and evaluate the growth prospects of the OECD countries. Section 6 concludes.

2 Framework for growth accounting

Per capita income growth in the OECD countries since the second industrial revolution is a complex mixture of transitional dynamics, demographic transition, and TFP growth along the balanced growth path. Figure 1 shows per capita growth rates in the 17 OECD countries that are considered throughout the paper since 1820. The countries are listed in the notes to the figure. The graph extends half a century further than the analysis in this paper to give insight into the growth regime that prevailed prior to 1870. The most important feature of the graph is that growth rates fluctuated around constant levels of about 1.5% up to WWII, grew by 4% from 1950 to 1973 and declined to 1.8% thereafter.



Notes. The following 17 countries (G17) are included in the table: Canada, the US, Japan, Australia, Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, and the UK. The population size is used as weights to calculate the weighted average. The data are smoothed using the Hodrick-Prescott filter with a smoothing parameter of 1600.

The economic environment in the 19th century was quite different from today. Agriculture was the dominant mode of production in most countries, the average working age adult had less than 2 years of education and worked twice as many hours per week as they do today, life expectancy at birth was less than half that of today, cross-country income dispersion was substantial, R&D was an informal activity not necessarily undertaken by individuals with a PhD, and the savings rate was less than 15 percent of GDP compared with 20 percent today.

Declining age dependency, rising educational attainment, increasing life expectancy, growing innovative activity, and increasing trade openness ensured that growth remained relatively constant despite high population pressure during most of the period up to WWII. A sharp reduction in the share of income generated in agriculture reduced the population growth drag after WWII. The spectacular growth rates experienced in the post-WWII period up to 1973, as shown below, were predominantly driven by an increase in the innovative activity, educational attainment and catch-up to the technology frontier for off-frontier countries.

This section combines all these factors into a joint framework that extends the models of Klenow and Rodriguez-Clare (1997) and Jones (2002) to allow for the demographic transition, changes in age dependency rates, changes in annual hours worked, and changes in labor force participation rates. First, consider the following homogenous three-factor Cobb-Douglas production function:

$$Y = AK^{\alpha}T^{\beta}H^{1-\alpha-\beta} = AK^{\alpha}T^{\beta}(hLZ)^{1-\alpha-\beta}, \quad (1)$$

where Y is output, A is TFP, K is capital, T is land area under cultivation, H is the total quantity of human capital used to produce output, L is employment, Z is annual hours worked, h is human

capital per worker, α is a fixed parameter, and β is a parameter that is allowed to vary over time. Human capital is computed following the Mincerian approach:

$$h = \exp(\theta s), \quad (2)$$

where θ is the returns to schooling and s is educational attainment, which is defined as the average years of schooling among the population of working age.

The production function can be written as:

$$\frac{Y}{L} = A^{1/(1-\alpha)} \left(\frac{K}{Y} \right)^{\alpha/(1-\alpha)} T^{\beta/(1-\alpha)} h^{(1-\alpha-\beta)/(1-\alpha)} Z^{(1-\alpha-\beta)/(1-\alpha)} L^{\beta/(1-\alpha)}. \quad (3)$$

Thus output per capita is given by:⁴

$$\frac{Y}{Pop} = \frac{L}{Pop^{LF}} \frac{Pop^{LF}}{Pop} A^{1/(1-\alpha)} \left(\frac{K}{Y} \right)^{\alpha/(1-\alpha)} T^{\beta/(1-\alpha)} h^{(1-\alpha-\beta)/(1-\alpha)} Z^{(1-\alpha-\beta)/(1-\alpha)} L^{\beta/(1-\alpha)}, \quad (4)$$

where Pop is the size of the population, Pop^{LF} is the population of working age, Pop^{LF}/Pop is the inverse age dependency rate and L/Pop^{LF} is the approximate labor force participation rate. Taking logs and differentiating Eq. (4) and using Eq. (2) yield the following per capita income growth rate, $g_{Y/Pop}$:

$$g_{Y/Pop} = \frac{1}{1-\alpha} g_A + g_{ER} - g_{Age} + \frac{\alpha}{1-\alpha} g_{K/Y} + \frac{\beta}{1-\alpha} g_T + \frac{1-\alpha-\beta}{1-\alpha} \Delta(\theta s) + \frac{1-\alpha-\beta}{1-\alpha} g_Z - \frac{\beta}{1-\alpha} n, \quad (5)$$

where g_A is the technology growth rate, g_{ER} is the growth in the employment rate, L/Pop^{LF} , $-g_{Age}$ is the growth in the age dependency rate, Pop/Pop^{LF} , $g_{K/Y}$ is the growth rate in the capital-output ratio, g_Z is the growth rate in annual hours worked, and n is the employment growth rate. In the growth accounting estimates, g_A is estimated residually from Eq. (5). The returns to schooling, θ , is set to 0.07 following Jones (2002).

Eq. (5) is one of the key equations in this paper and requires some discussion. First, the first term in Eq. (5) is TFP-induced growth in steady state. The other terms are either transitional dynamics or the interaction between population growth and land, which over a very long perspective may be considered as transitional dynamics. There is no one-to-one relationship between growth in TFP and per capita income as there is in simple growth accounting models. TFP-

⁴ Klenow and Rodriguez-Claire (1997) write Equation (4) without land but with (H/Y) as a right-hand-side variable instead of h under the maintained hypothesis that (H/Y) is constant along the balanced growth path in the two-sector model of Lucas (1988). (H/Y) is constant along the balanced growth path because technological progress increases the returns to schooling and induces students to increase their human capital until it equals the time preference. The problem with this approach is that human capital, unlike reproducible capital, cannot easily be increased after individuals leave schools and the lack of access of credit to finance schooling. In any event, since h is used as a proxy for (H/Y) in Klenow and Rodriguez-Claire's empirical estimates, it makes no difference whether h or (H/Y) is used in the computations.

induced growth effects are magnified by a factor of $1/(1-\alpha)$ because the endogeneity of capital deepening is allowed for.

Second, following Klenow and Rodriguez-Clare (1997) and Jones (2002), the growth accounting in Eq. (5) is in terms of the K - Y ratio and not as the K - L ratio as in conventional growth accounting exercises. Thus, the fraction of capital deepening that is TFP-induced is attributed to TFP growth and not capital as in traditional growth accounting exercises. As shown by Madsen and Davis (2006) and Madsen (2010) capital deepening is influenced by TFP because technological progress increases expected earnings and, through the channel of the share market, causes Tobin's q to exceed of its steady state value. This initiates a capital deepening process that terminates when Tobin's q reaches its steady state equilibrium.

Third, Eq. (5) does not give insight into the factors that are driving the K - Y ratio outside the balanced growth path. Based on an asset pricing model with no taxes, Madsen and Davis (2006) and Madsen (2010) show that the K - Y ratio is driven by required stock returns, which are in turn driven by the time preference. A reduction in required stock returns results in expected earnings that are capitalized at a lower rate and, therefore, in stock prices and Tobin's q that are in excess of their steady state levels. This results in capital accumulation that terminates when Tobin's q has reached its steady state.

Fourth, standard growth theories predict or assume that that the capital-income ratio, educational attainment, age dependency rates, annual hours worked, and labor force participation rates are constant along the balanced growth path. However, these factors have changed substantially since the Second Industrial Revolution, which suggests that transitional dynamics has been an important part of the OECD economies' growth experience since 1870.

Fifth, population growth is a drag on per capita growth because of diminishing returns introduced by land as a semi-fixed factor of production. In contrast to reproducible capital, land usage cannot easily be expanded in response to higher returns to land induced by population growth. When a factor of production has inelastic supply it is not the quantity of the factor that responds to higher demand but its price. Reproducible capital, for example, will automatically respond to population growth through the Tobin's q mechanism as described above, so that the K - L ratio remains unaffected by population growth along the balanced growth path. In an agrarian economy population growth, by contrast, reduces per capita output through a reduced T - L ratio provided that the additional labor force is not channeled into the R&D sector. As the economy develops, β approaches zero and population growth becomes unimportant for growth along the balanced growth path. For the countries considered in this study the average β was 0.36 in 1870 and has since declined gradually to the tiny figure of 0.02 in 2006. The importance of agriculture in economic activity up to the 1960s has rendered population growth potentially influential for growth

over a large fraction of the time-span considered here. If land is absent from production, i.e. $\beta = 0$, the model collapses to a standard growth model where per capita growth at steady state is equal to TFP growth.

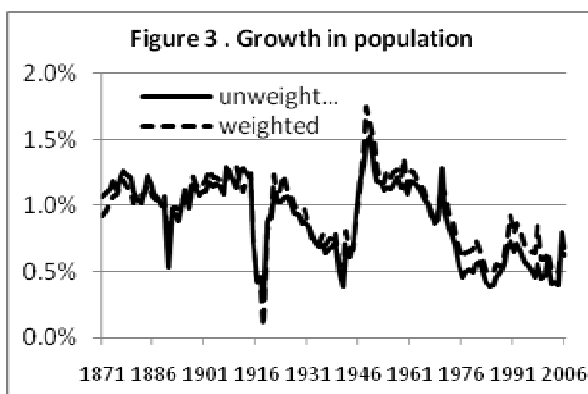
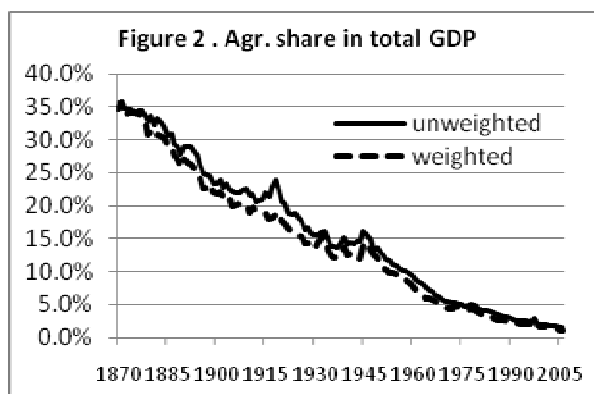
Sixth, human capital is, for simplicity, treated exogenously and independently of growth because the increase in educational attainment over the past 137 years has, to some extent, been driven by an increase in the length of compulsory schooling. Since education is partly determined by expected growth, as argued by Bils and Klenow (2001), the effects of education on growth are likely to be exaggerated in this framework.

Seventh, growth in A is implicitly treated exogenously in Eq. (5). However, it needs to be explained to give deeper insight into the principal sources of growth and, particularly, whether there are scale effects in ideas production and, therefore, whether R&D and educational attainment have permanent or temporary growth effects. The currently most accepted second-generation endogenous growth models, namely semi-endogenous and Schumpeterian growth theories, have different predictions about scale effects in knowledge production. Section 4 examines the determinants of TFP growth.

3 Accounting for growth

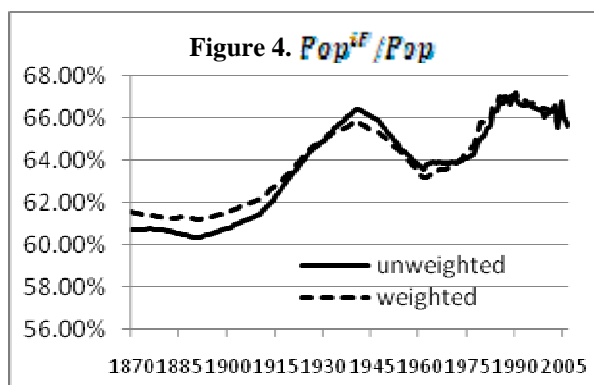
3.1 Graphical evidence

The data used for the growth accounting exercise are shown in Figures 2 to 7. Figure 2 shows that the share of agriculture in total GDP has gradually declined from 35 percent in 1870 to 2 percent in 2006. Combined with the reduced share of agriculture in total GDP the population growth drag was significantly reduced during WWI when the trend in the population growth rate almost halved (Figure 3). Although this bounced back to its pre-WWI level during the period 1946-1975 its drag on per capita income growth was substantially reduced along with the share of agriculture in total output. Today population growth hardly influences per capita income growth in steady state in the framework developed in the previous section, because agriculture represents only a small fraction of economic activity.



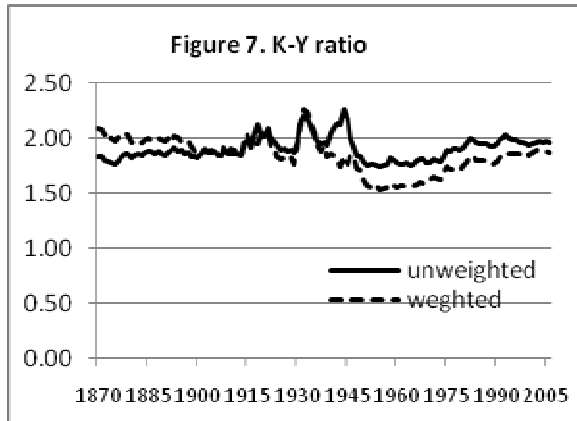
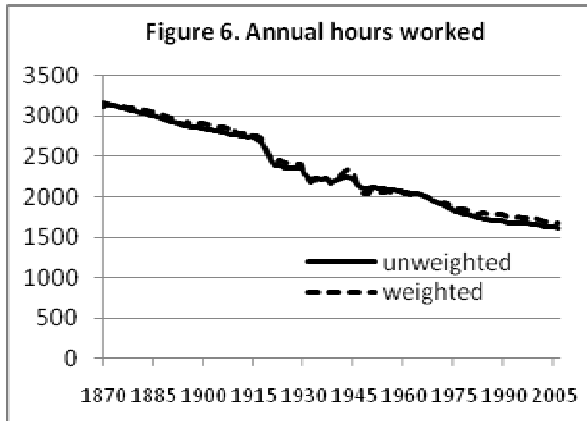
Note. See notes to Figure 1.

Figure 4 shows that the age dependency ratio (share of population outside working age) declined at the beginning of the last century; thus contributing positively to per capita growth during that period. This reduction was predominantly driven by a declining fertility. The post-WWII baby boom increased the age dependency ratio over the period from 1945 to 1960. It reached a historical low around 1990 and has only increased slightly since then. Figure 5 shows that the employment rate today is approximately the same as it was in 1870. The 19th century employment rate has first been established today after the reductions during the Great Depression and the post-WWII recession. This constancy of the employment rate over the very long run is remarkable in the light of the general perception of a marked upswing in the female labor force participation rate in the 1960s.



Annual hours worked have on average declined from 3200 hours in 1870 to 1600 in 2006 (Figure 6), which has reduced per capita income by a half from a growth accounting perspective. Apart from a significant jump immediately after WWI, probably as a response to the Russian Revolution, the decline in hours worked has been fairly gradual. The K - Y ratio has remained relatively constant for the overall period considered (Figure 7), probably indicating a relatively constant time-preference. Low investment during the Great Depression and the destruction of capital during

WWII reduced the ratio by approximately 25 percent during these periods. The subsequent increase up to 1975 contributed to per capita growth over the same period.



3.2 Growth accounting results

Table 1 decomposes growth into its components following Eq. (5). The following four distinctive periods are considered: 1870-1913, 1913-1950, 1950-1973 and 1973-2006. During the Second Industrial Revolution (1870-1913), per capita income growth rate was on average 1.42%. Growth in TFP, expanding land usage, and improved education contributed positively to growth while population growth and the declining annual hours worked jointly reduced the annual growth rate by 0.61 percentage points. Although the pace of technological progress kept the TFP growth rate constant between the periods 1870-1913 and 1913-1950 per capita growth rates were reduced because of the marked reduction in annual hours worked, the cessation of expanding land usage and reduced employment ratios that were probably a result of increasing unemployment rates.

Table 1. Decomposition of per capita growth rates for the OECD countries (Eq. (5)).

	$g_{Y/Pop}$	g_A	g_{ER}	g_{AGE}	$g_{K/Y}$	g_T	$\Delta(\theta_s)$	g_Z	n
1870-1913	1.42	1.46	-0.03	0.05	0.05	0.26	0.24	-0.33	-0.28
1913-1950	1.16	1.48	-0.13	0.14	0.12	0.03	0.37	-0.68	-0.16
1950-1973	3.88	3.81	0.24	-0.01	0.02	0.00	0.54	-0.55	-0.09
1973-2006	1.86	1.11	0.21	0.10	0.25	0.00	0.66	-0.45	-0.02

Notes. The growth rates are annual geometric growth rates and are unweighted averages of the 17 countries listed in the notes to Figure 1.

The spectacular per capita growth rates during the period 1950-1973 were almost entirely driven by TFP growth. Increasing employment rates and educational attainment were also influential. In the period 1973-2006 increasing $K-Y$ ratios, employment rates and educational attainment jointly contributed to more than one percentage points to per capita growth while TFP growth only contributed to a 1.11 percentage points, which is a sharp reduction in the TFP growth rates experienced in the period 1950-1973 and lower than those prior to 1950.

Table 2 decomposes growth in the US, the UK, Japan and Germany. These countries are not only important because of their sheer size but also because they are interesting on their own right. Only the most important terms in Eq. (5) are shown to preserve space. Relative to the OECD average the US experienced strong TFP growth rates up until 1950 and low rates thereafter. The post-1973 period is particularly concerning for the US because TFP growth has only contributed 0.79 percentage points to growth. Despite the poor TFP growth rates in the post-1973 period per capita growth rates in the US have remained comparable to those over the last century because of markedly increasing employment and educational attainment rates and because working hours ceased to decrease unlike most other OECD countries.

Table 2. Decomposition of per capita growth rates for USA, Japan, Germany and the UK.

	USA						Japan					
	$g_{Y/Pop}$	g_A	G_{ER}	g_{KY}	$\Delta(\theta_s)$	g_Z	$g_{Y/Pop}$	g_A	G_{ER}	g_{KY}	$\Delta(\theta_s)$	g_Z
1870-1913	1.80	1.72	0.14	-0.15	0.35	-0.49	1.50	1.32	-0.27	0.71	0.18	-0.26
1913-1950	1.60	2.23	0.02	-0.38	0.61	-0.74	0.94	2.07	-0.40	0.22	0.51	-1.22
1950-1973	2.26	2.30	0.27	-0.55	0.61	-0.13	8.00	6.21	-0.14	0.52	0.83	0.18
1973-2006	1.88	0.79	0.51	-0.15	0.70	-0.01	2.09	1.09	0.13	0.97	0.61	-0.58
	Germany						UK					
1870-1913	1.62	1.66	0.14	-0.05	0.31	-0.23	0.93	0.66	0.22	-0.19	0.41	-0.09
1913-1950	0.30	0.85	-0.39	-0.21	0.36	-0.37	0.67	0.69	-0.10	0.03	0.50	-0.61
1950-1973	5.02	5.50	0.39	0.03	0.40	-1.03	2.51	2.32	0.14	0.23	0.52	-0.41
1973-2006	1.64	1.73	-0.06	0.18	0.45	-0.80	2.01	1.25	0.31	0.44	0.54	-0.52

Japan is a very interesting case. Its per capita income was well below the OECD average until the 1950s. However, its comparatively poor growth performance before 1950 was *not* due to a slow pace of technological progress. In fact, Japan's TFP growth rates exceeded the OECD average. Japan's relatively slow growth performance was a result of falling employment rates and, particularly, a significant population growth drag due to spectacularly high fertility rates during that period. In the same way the US, Japan's post-1973 TFP growth rates have been low relative to the OECD average and its past, and half this growth has been driven by non-TFP induced capital deepening. If Japan's TFP growth rates do not pick up, it is likely to be stuck in a low growth trap like the US.

The spectacular growth rates in Germany and Japan in the period 1950-1973 have often been attributed to the transitional growth effects of capital deepening following the destruction of capital during WWII. The results in Table 2 show that the increasing $K-Y$ ratio contributed little in this period. Almost all growth can be attributed to a marked increase in TFP, which suggests that their growth rates were truly miraculous. Finally, the low per capita income growth rates experienced in the UK up to 1973 are attributed almost entirely to slow TFP growth rates.

4. Growth regressions

The growth decomposition in the previous section showed that TFP growth explains the lion's share of per capita growth in the OECD in the post WWII period and exceeded per capita income growth in the period 1870 to 1950. This section takes the analyses a step further by explaining TFP and labor productivity growth rates in terms of R&D, human capital, international knowledge spillovers, population growth and capital deepening. The model is designed to test whether there are scale effects in knowledge production and, therefore, whether per capita income will continue to grow into the future for a given R&D and human capital intensity.

The following empirical model is formulated in general terms to encompass the predictions of the most important endogenous growth models:

$$\begin{aligned} \Delta \ln(Y/L)_{it} = & \varphi_0 + \varphi_1 ea_{it} + \varphi_2 \Delta ea_{it} + \varphi_3 \Delta \ln X_{it}^d + \varphi_4 \Delta \ln X_{it}^f + \varphi_5 \ln \left(\frac{X}{Q} \right)_{it}^d + \varphi_6 \ln \left(\frac{X}{Q} \right)_{it}^f \\ & + \varphi_7 ea_{it} DTF_{it} + \varphi_8 \left(\frac{X}{Q} \right)_{it}^d DTF_{it} + \varphi_9 \Delta \ln \left(\frac{K}{Y} \right)_{it} + \varphi_{10} \frac{\beta_{it}}{1-\alpha} n_{it} + CD + \varepsilon_{it}, \end{aligned} \quad (6)$$

where the superscripts d and f stand for domestic and foreign, X is the innovative activity, Q is product variety, (X/Q) is research (patent) intensity, ea is educational attainment, CD is country-dummies, ε is a stochastic error term, and $DTF = [\bar{A}_{t-1} - A_{t-1}] / A_{t-1}$ is the distance to frontier, where \bar{A} is TFP at the world technological frontier and is measured as the maximum TFP of the US and the UK.

Here, X is measured by patent applications because it is a reasonable good measure of research activity (Griliches, 1990) and because it is the only available measure of the innovative activity that dates back to 1870. Research intensity is measured by patent applications divided by employment following Madsen (2008a). Land's income share is allowed to change over time as the importance of agriculture has diminished along with the modernization. Following Denison (1967) β_{it} is estimated as the share of agriculture in total GDP. The dependent variable is either measured as output per hour worked or as TFP. Output per hour worked is used as a complement to TFP in the estimates as a double check on the reliability of the estimates and to verify whether the social returns equals the private returns to factors of production as assumed in the growth accounting exercise.

R&D knowledge is assumed to be transmitted internationally through the channel of imports $[(X/Q)^f$ and $X^f]$ and by the interaction between the absorptive capacity and the distance to the frontier ($ea \cdot DTF$ and $(X/Q)^d DTF$). The import channel follows the endogenous models described in Grossman and Helpman (1991) and support for this mode of transmission is found by Coe and Helpman (1995) and Madsen (2007, 2008b), among others. These models use the stock of domestic

and foreign knowledge, S^d and S^f , respectively as regressors instead of the flow of knowledge, X^d and X^f , shown in Eq. (6). The stock of knowledge is used instead of X^d and X^f only in some of the regressions below, because the semi-endogenous growth models predict that the productivity level is affected by X and not by S .

The predictions of the two leading second-generation models of endogenous growth, such as semi-endogenous and Schumpeterian growth models, are accommodated in the estimates. The semi-endogenous growth theory of Jones (1995, 2002) abandons scale effects in ideas production, which implies that R&D and educational attainment have only temporary growth effects as captured by the two terms $\Delta \ln X^d$ and $\Delta \ln X^f$ in Eq. (6). The Schumpeterian growth models of Aghion and Howitt (1998), Peretto (1998), Howitt (1999), and Peretto and Smulders (2002) maintain the scale effects from first-generation endogenous growth models but assume that the effectiveness of R&D dilutes due to the proliferation of products as the economy expands. Thus, growth is driven by research intensity in the Schumpeterian models. Patents are divided by employment to allow for product proliferation. In steady state the number of product lines is proportional to the size of population. To ensure sustained growth the number of patents has to increase over time to counteract the increasing range and complexity of products that lowers the productivity effects of R&D activity.

Similarly, the Schumpeterian model of Aghion, Meghir and Vadenbusche (2006) and the fully endogenous model of Lucas (1988) predict that TFP growth is proportional to the log of educational attainment, which implies that the growth rate will remain positive in the future due to positive educational attainment; even if R&D intensity goes toward zero. Semi-endogenous growth theory by contrast abandons scale effects in ideas production. This implies that TFP growth is proportional to the growth rate in R&D and educational attainment. Levels of R&D and educational attainment, therefore, cannot have permanent growth effects.

Growth is positively related to the interaction between the absorptive capacity and the distance to the technology frontier. Barro and Sala-i-Martin (2004, Ch. 8), for example, argue that the effective cost of innovation and technology adoption falls the further away from the technology frontier a country is. Easterlin (1981) observes that high productivity nations have used the same technology throughout history and that Japan modernized in the Meiji restoration period using Western technology. However, the limited diffusion of technology may explain the differential technological change for off-frontier nations. Easterlin (1981) argues that technology must be taught and learned and that the labor force must be educated to master new technological knowledge that has been developed elsewhere. Thus, as long as a country with good institutions has an educated labor force and invests in R&D it will be able catch-up to the frontier countries.

The absorptive capacity is measured by educational attainment and research intensity. The interaction between absorptive capacity, measured by educational attainment, and the distance to the frontier follows the predictions of the Nelson-Phelps (1966) model. The philosophy behind the Nelson-Phelps model is that the further a country is behind the technological frontier the higher is its growth potential, provided that it has a sufficiently high level of human capital, or absorptive capacity, to take advantage of its backwardness. Similarly, the term representing interaction between research intensity and the distance to the frontier captures the idea that off-frontier countries benefit from their backwardness provided that they invest in R&D following the historical analysis of Gerschenkron (Howitt, 2000). In Howitt's (2000) model it is R&D intensity that draws a country to the technology frontier and the higher the intensity the faster the convergence.

4.1 Data

4.4.1 Productivity

The economy-wide TFP data are based on the three-factor homogenous Cobb-Douglas production technology. Following the Divisa-Törnqvist method, the land shares are allowed to vary over time and across countries:

$$TFP_{it} = \frac{Y^r}{H_{it}^{(1-\alpha)} K_{it}^{\alpha(1-s_{it})} T_{it}^{\alpha s_{it}}} \quad (7)$$

where Y^r is real GDP, H is educational attainment (see Eq. (2)) and hours worked (annual hours worked times economy-wide employment), K is capital stock, T is land area under cultivation, $(1-\alpha)$ is labor's income share for country i , s is the agricultural sector's share of the economy-wide GDP, which is allowed to vary across countries and over time following the method suggested by Denison (1967, p. 41) in which the output elasticity of land is measured as the share of agriculture in total GDP. While land is not an important factor of production for the industrial countries today, it was an essential production factor before the mid 20th century. The unweighted average of the share of agriculture in total GDP has declined from 37% in 1870 to 2% in 2002 for G17 countries. This underscores the importance of including land as a factor of production in the TFP estimates that go far back in history. **The data are detailed in the data appendix.**

TFP is measured in three different ways. First, it is measured without land and educational attainment and capital's income share is fixed at 0.2 (TFP^A). Second, it is measured inclusive land and educational attainment with capital's share fixed at 0.2 (TFP^B). Third, it is measured excluding land and educational attainment with capital's share fixed at 0.3 (TFP^C). Capital's income share is in the range of 0.2 and 0.3 following the estimates of Gollin (2002). Making adjustment for self-employed and other factors Gollin (2002) finds that capital's share varies within the range of 0.20-

0.35. These income shares are supported by the estimates below. Capital's income share is kept constant over time because data on income shares are only available over a limited period and because changes in income shares are more likely to reflect changes in rent than changes in the relative marginal productivities. Hall (1988), for example, has shown that capital is paid in excess of its marginal productivity in the US. It is also well-known that labor's increasing income share in the 1970s did not reflect increasing labor productivity but that labor increased its share of rent (see for example Madsen, 1998).

Estimating historical levels of human capital is a momentous task and requires data on population distribution by age groups and school enrolment that span back to 1812. The method used here is based on the gross enrolment rate (GER), which is the fraction of the population in a certain age cohort that is enrolled at a certain educational level. The GER for primary, secondary and tertiary school enrolment is estimated for each age cohort. Educational attainment in one particular year is then estimated as the average of the educational attainment for each age cohort in the labor force. The data are adjusted for the length of the school year and school attendance rates.

The estimation method and data sources are detailed in the data appendix.

4.1.2 International knowledge spillovers

Knowledge spillovers through the channel of imports of intermediate products that contain new technology from country j to country i are computed from the following weighting scheme suggested by Lichtenberg and van Potterie (1998):

$$S_{it}^f = \sum_{j=1}^{21} \left(\frac{M_{ijt}}{Y_{jt}^n} \right) S_{jt}^d, \quad i \neq j. \quad j = 1, 2, \dots, 21.$$

where M_{ijt} is nominal imports of goods of high-technology products from country j to country i , Y_j^n is nominal income of country j and S^d is the stock of domestic knowledge, which is estimated using the perpetual inventory method and a 20% depreciation rate (see data appendix for details). The 21 countries used to estimate knowledge spillovers consist of the G17 and New Zealand, Greece, Ireland, and Portugal. The following SITC classifications for high technology products are used after WWII: Chemicals and related products (SITC Section 5), machinery and transport equipment (SITC Section 7), and professional and scientific instruments (SITC Section 8.7). Total bilateral trade is used before WWII due to data availability.

For the R&D flows the following weighting schedules are used (see Madsen, 2008a):

$$\left(\frac{R}{Q} \right)_{it}^f = \sum_{j=1}^{21} \frac{m_{ijt}}{m_{it}} \left(\frac{R}{Q} \right)_{jt}^d, \quad i \neq j \quad \text{Schumpeterian growth theory}$$

$$X_{it}^f = \sum_{j=1}^{21} \frac{m_{ijt}}{m_{it}} \tilde{X}_j^d, \quad i \neq j \quad \text{Semi-endogenous growth theory}$$

where m_{ij} is country i 's imports of high-technology products from country j , m_i is country i 's total imports of high technology products, and \tilde{X}_j is X_j indexed to one in 1995 for each individual country to ensure that large countries do not have a higher weight in the index than smaller countries.

4.2 Estimation method

Eq. (6) is estimated using pooled cross-section and time-series analysis. The data cover the period from 1870 to 2006 for the G17 countries. The estimates are in five-year differences. Results from estimates in 10-year and 15-year differences are not reported because they give almost the same results as the regressions in five-year differences. To gain efficiency and to correct for serial correlation and heteroscedasticity, the covariance matrix is weighted by the correlation of the disturbance terms using the variance-covariance structure as follows:

$$\begin{aligned} E\{\varepsilon_{it}^2\} &= \sigma_i^2, \quad i = 1, 2, \dots, N, \\ E\{\varepsilon_{it}, \varepsilon_{jt}\} &= \sigma_{ij}, \quad i \neq j, \\ \varepsilon_{it} &= \rho \varepsilon_{it-1} + v_{it} \end{aligned}$$

where σ_i^2 is the variance of the disturbance terms for country $i = 1, 2, \dots, N$, σ_{ij} is the covariance of the disturbance terms across countries i and j , ε is the disturbance term and v is an *iid* disturbance term. The variance σ_i^2 is assumed to be constant over time but to vary across countries and the error terms are assumed to be mutually correlated across countries, σ_{ij} , as random shocks are likely to impact all countries at the same time. The parameters σ_i^2 , ρ and σ_{ij} are estimated using feasible generalized least squares.

4.3 Regression results

The results of regressing Eq. (6) are presented in Table 3. The results show that educational attainment, R&D and the distance to the frontier are all statistically highly significant determinants of growth. Both estimated coefficients of the level and the change in educational attainment are highly significant in all regressions. Although the change in educational attainment is a significant determinant of growth the regression results are not consistent with the predictions of semi-endogenous growth theory because the level of educational attainment has permanently positive

growth effects. The implication of these results is that a one-off change in educational attainment has higher growth effects in the short run than in the long run.

Table 3. Restricted and unrestricted parameter estimates of Eq. (6) in 5-year differences.

	1	2	3	4	5	6	7	8
Dep. var.	Y/L	Y/L	TFP^A	TFP^A	TFP^B	TFP^B	TFP^C	TFP^C
ea_t^d	0.04 (5.34)	0.03 (4.73)	0.03 (5.96)	0.03 (5.21)	0.02 (3.62)	0.02 (2.95)	0.03 (5.25)	0.03 (4.61)
Δea_t^d	0.20 (6.88)	0.20 (6.56)	0.15 (6.08)	0.13 (5.11)	0.11 (4.11)	0.08 (3.07)	0.08 (3.72)	0.06 (2.64)
$\Delta \ln X_t^d$		0.014 (1.99)		0.015 (2.93)		0.013 (2.42)		0.014 (3.35)
$\Delta \ln X_t^f$		0.04 (7.50)		0.03 (6.79)		0.03 (6.68)		0.03 (6.72)
$\Delta \ln S_t^d$	0.04 (4.72)		0.04 (5.42)		0.04 (4.47)		0.04 (5.42)	
$\Delta \ln S_t^f$	0.02 (6.26)		0.02 (6.47)		0.02 (7.29)		0.02 (7.08)	
$\ln Q/Q_t^f$	0.01 (3.54)	0.010 (3.08)	0.007 (2.48)	0.006 (2.26)	0.006 (2.03)	0.005 (1.76)	0.006 (2.18)	0.006 (2.11)
$\ln Q/Q_t^d$	0.003 (0.61)	0.002 (0.32)	0.009 (1.55)	0.008 (1.30)	0.014 (2.46)	0.0014 (2.26)	0.010 (1.69)	0.008 (1.42)
$ea^d \cdot DTF_{t-1}$	0.006 (8.52)	0.006 (8.27)	0.006 (8.13)	0.006 (7.71)	0.006 (6.94)	0.006 (6.59)	0.006 (8.31)	0.006 (7.83)
$(X/Q)^d$ DTF_{t-1}	-0.012 (2.20)	-0.013 (2.14)	-0.013 (2.32)	-0.009 (2.38)	-0.003 (0.57)	-0.003 (0.44)	-0.013 (2.46)	-0.014 (2.72)
$\Delta \ln(K/Y)$	0.005 (3.21)	0.007 (4.00)	0.003 (1.82)	0.004 (2.33)	0.003 (1.75)	0.004 (2.09)	0.001 (0.89)	0.002 (1.35)
$\frac{\beta_{1t} n_{1t}}{1 - \alpha}$	-1.06 (7.71)	-0.89 (5.70)						
DW	1.99	1.98	2.00	2.01	2.00	2.00	2.01	2.02
$R^2(\text{Buse})$	0.75	0.75	0.67	0.69	0.52	0.56	0.66	0.67

Notes. The numbers in parentheses are absolute t -statistics. The following years are included in the estimates: 1875, 1880, 1890, 1895, 1900, 1905, 1910, 1915, 1920, 1925, 1930, 1935, 1940, 1951, 1956, 1961, 1966, 1971, 1976, 1981, 1986, 1991, 1996, 2001, and 2006. DW = Durbin-Watson test for first-order serial correlation. $R^2(\text{Buse})$ = Buse's multiple correlation coefficient. (K/Y) is instrumented using a one period lag of (K/Y) , time-dummies, and a one period lag of the short interest rate. TFP^A = TFP without land and educational attainment and capital's share fixed at 0.2, TFP^B = TFP including land and educational attainment and capital's share fixed at 0.2, and TFP^C = TFP excluding land and educational attainment and capital's share is fixed at 0.3.

Almost all the estimated coefficients of the domestic R&D variables are statistically significant. Productivity growth is positively affected by the change in the flow and the stock of patents and the patenting intensity. The results are not sensitive to whether the research activity is measured as stocks or flows (i.e. X^d and S^d). The estimated coefficients of X^d and S^d are mostly highly significant and the other parameter estimates in the regressions are almost the same regardless of whether X^d or S^d are used in the regressions. The estimated coefficients of patenting intensity are significant at conventional significance levels as predicted by Schumpeterian growth theory. As for educational attainment, R&D has permanent growth effects. The short-term growth effects of a change in R&D or the R&D stock are larger than the long-term effects.

The estimated coefficients of R&D spillovers through the channel of import are mostly positive and significant. All the coefficients of X^f and S^f are statistically highly significant, which suggests that knowledge spillovers through the channel of imports are influential for the level of

productivity. However, the regression results indicate the absence of permanent growth effects of international knowledge spillovers as the estimated coefficients of $(X/Q)^f$ are mostly insignificant.

The estimated coefficients of the interaction between educational attainment and the distance to the frontier are 0.006 and are statistically and economically highly significant in all the estimates in the table. For a country that is 10% below the technology frontier and with an educational attainment of five years of schooling this interaction term contributes to a 0.06% productivity growth every year. This result suggests that the interaction between human capital intensity and the distance to the frontier has substantial growth effects in countries that are significantly below the technology frontier. The interaction between these terms has particularly, been influential for growth in Japan and Finland before WWII.

The estimated coefficients of the K - Y ratio are statistically significant in the estimates in the first two rows in which labor productivity is the dependent variable; however, they are well below the model predictions of $1/4$ or $3/7$ (income shares of 0.2 and 0.3, respectively). The low coefficient estimates may reflect that the services derived from capital stock and the capital stock are measured with large measurement errors, low social returns to capital or that capital deepening has not been an important factor explaining the OECD growth experience over the past 137 years; particularly not when taking into account that the K - Y ratio has only increased slightly since 1870 (see Table 1). The estimated coefficients of the K - Y ratio are either insignificant or only marginally significant in the regressions in which TFP is the dependent variable, which suggests that factor shares used in the TFP estimates are appropriate.

Finally, the estimated coefficients of population growth are highly significant and consistent with the theory predictions. The coefficient estimates of -1.06 and -0.89 are very close to the prediction of -1 in the model in Section 2. This result reinforces the hypothesis that population growth was a drag on growth in the OECD economies before the industrial development gained momentum in the post WWII period.

5 The anatomy of post 1870-growth

This section assesses the quantitative importance of each individual explanatory variable in Eq. (6) to gain insight into which factors have been responsible for growth over the past 137 years. Table 4 shows the simulations of labor productivity growth based on the regression in column 2 in Table 3. The data are annualized geometric growth rates and approximately cover the periods in Tables 1 and 2. The growth effects of $(X/Q)^d DTF_{t-1}$ are almost zero and, consequently, omitted from Table 4. Variations in the K - Y ratio have had negligible effects on growth and the population growth drag was 0.17 percentage points during the period 1875-1915 and insignificant thereafter. The TFP related factors, however, have been influential for growth. Educational attainment has been

influential for growth through its level effect, its growth effect and its interaction with the distance to frontier. Through these three channels education has contributed to 2-2.5 percentage points of growth during each of the periods considered in the table. Research intensity and the growth in patents have also been influential for growth and contributed to almost one percentage point growth during the whole period. Educational attainment and research intensity have been the two consistently significant contributors to growth during the whole period 1870-2006.

Table 4. Decomposition of output per hour worked growth rates for the OECD countries (Eq. (6)).

	$g_{Y/L}$	Ea	Δea	$\Delta \ln X^d$	$\Delta \ln X^f$	$\ln(X/Q)^d$	$g_{K/Y}$	$ea*DTF$	n
1875-1915	1.57	0.81	0.49	0.31	0.14	0.54	0.01	0.71	-0.17
1915-1950	1.80	1.31	0.35	0.06	0.00	0.77	0.02	0.87	-0.04
1950-1975	4.09	1.67	0.20	0.04	0.13	0.79	0.02	0.66	-0.09
1975-2006	1.92	1.92	0.16	0.03	0.05	0.75	0.02	0.31	-0.01

Notes. The growth rates are annual geometric growth rates and are unweighted averages of the 17 countries listed in the notes to Figure 1. The simulations are based on the regression in the second column in Table 3. The figures are unweighted averages.

The period 1950-1975 stands out as a period with exceptionally high TFP-induced productivity growth rates. High and growing educational attainment intensity, growing knowledge spillovers through the channel of imports, catch up to the technology frontier and the research intensity all contributed to the spectacular TFP growth rates. The productivity slowdown after 1975 is predominantly a result of the lack of any significant population growth drag, an almost completed convergence among the G17 countries, and a slowdown in the growth in imports of knowledge and educational attainment.

Based on the estimates in the previous section the anatomy of growth during the period 1870 to 2006 can be summarized as follows. The industrialized countries first entered the modern growth regime around 1870, during the Second Industrial Revolution (Galor, 2005). School enrolment, attendance rates, and the length of the school year increased markedly during the period from 1870 to WWI and contributed to an increasing number of educated individuals entering the work force. Increasing innovative activity has also been a key factor behind the positive productivity growth in the OECD countries since the Second Industrial Revolution. Furthermore, the expanding trade combined with an increasing educational attainment contributed significantly to growth during that period. Finally, the large cross-country discrepancies between TFP levels in 1870 gave the most backward countries a good opportunity to take advantage of the knowledge of the frontier countries provided that they were able and willing to expand the educational achievement among new entrants to the labour market.

6 Concluding remarks

Using endogenous growth accounting this paper has shown that several factors have contributed to per capita growth in the OECD countries since 1870. These factors are human capital, innovative activity, the interaction between absorptive capacity and the distance to the frontier, transmission of knowledge through the channel of imports, population growth, land usage, capital deepening, age dependency ratios, and labor force participation rates. In contrast to most growth accounting exercises capital deepening was found not to have been an unimportant source of growth after it was taken into account that most capital deepening over the past 137 years has been TFP-induced. Similarly, labor force participation rates and land usage have remained relatively constant over the past 137 years and, as such, have not been influential for growth.

The principal sources of growth since 1870 have been demographic transition and TFP growth. The demographic transition around WWI resulted in sharp reduction in population growth rates and, consequently, in a reduced age dependency ratio. Before WWI the population was a drag on the economy because of diminishing returns introduced by land as a fixed factor of production. Although the population growth rate increased to its pre-WWI level in the period 1946-1973 as a result of increasing life expectancy and the post-WWII baby boom it had by then diminished as a drag on the economy along with modernisation. However, the resulting increase in the age dependency ratios has not affected the per capita income growth rates adversely.

TFP growth has been the overwhelming force behind growth since the OECD countries entered a modern growth epoch around 1870. It was shown that the increasing educational attainment and research intensity, knowledge spillovers through the channel of imports, and the interactions between educational attainment and the distance to the frontier were all influential for growth. Importantly, the regressions gave credence to Schumpeterian growth theories and, therefore, the view that educational attainment and R&D (intensity) have permanent growth effects.

Although the high rates of research intensity and educational attainment reached today will continue to produce significant permanently positive TFP growth rates the prospects for the OECD are likely to deteriorate. Per capita income growth rates will probably diminish in the future because the aging of the population is likely to be a large drag on the economy and because the positive growth effects from educational attainment, import of knowledge and convergence will either cease or slow down substantially. Furthermore, the sharp increase in the price of risk induced by the global financial crisis is likely to lower the K - Y ratio over the next few decades, and, consequently, reduce growth rates even further. Unless there is an increase in the retirement age, the labor force participation rate or the annual hours worked, per capita growth rates will be reduced substantially in this century compared to the previous century.

Data appendix

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Capital stock of equipment and non-residential structures. The perpetual inventory method is used with the following depreciation rates: 17.6% for machinery and equipment, and 3% for non-residential buildings and structures. The stock of capital is initially set to the Solow model steady state value of $I/(\delta + g)$, where I is investment, δ is the depreciation rate and g is the growth in investment during the period from 1870 to 2004. The post 1960 data are from OECD, *National Accounts, Vol. II*, Paris, (NA). Before 1950 the following sources are used for the countries for which historical data are available. Canada. 1870-1900: Both types of investment are assumed to follow total non-residential investment in nominal prices deflated by the CPI. 1901-1925: 5-year average disaggregated into 1-year intervals using total non-residential investment deflated by CPI. Source: F. H. Leacy *et al.*, 1983, *Historical Statistics of Canada*, Ottawa: Statistics Canada. United States. A. Maddison, 1995, *Explaining the Economic Performance of Nations*, Edward Elgar. Japan. 1885-1988: A. Maddison, 1995, *op. cit.*, Backdated to 1870 using the growth rate in total investment from A. Maddison, 1995, *op. cit.*, 25.7% war damage to the 1945 capital stock is incorporated into the capital stock following A. Maddison, (1995, *op. cit.* Australia: 1863-1902: C. Clark, 1970, “Net Capital Stock,” *Economic Record*, pp. 449-466. 1903-1950: M. W. Butlin, 1977, *A Preliminary Annual Database 1900/01 to 1973/74*, Research Discussion Paper 7701, Reserve Bank of Australia: Sydney. Belgium. M. van Meerten, 2003, *Capital Formation in Belgium, 1900-1995*, Leuven: Leuven University Press. Before 1900: The ratio of investment and GDP in 1900 multiplied by real GDP is used backdated to the data to 1870. War damage correction: WWI. 15.5% of 1913 GDP spread out evenly between the years 1914-1917. WWII 7.1% spread out evenly for the years 1943-45. The correction for war damage follows M. van Meerteen, 2003, *op. cit.* (see his footnote no. 39). Denmark: 1870-1950: K. Bjerke and Nils Ussing, 1958, *Studier Over Danmarks Nationalprodukt 1870-1950*, G. E. C. Copenhagen :Gads Forlag. Finland. R. Hjerpe, 1989, *The Finnish Economy, 1860-1985*, Helsinki: Bank of Finland, Government Printing Centre. France. 1856-1895: Total

investment deflated by industry prices. E. Chadeau, 1989, *l'Economie Nationale Aux XIX et XX Siecles*, Paris: Presses de l'Ecole normale Supérieure. 1896-1914 and 1921-1938: J-J. Carre P. Dubois and E. Malinvaud, 1975, *French Economic Growth*, Stanford: Stanford University Press. 1914-1921 and 1939-1949: Crude steel production adjusted. T. Liesner, 1989, *One Hundred Years of Economic Statistics*, Oxford: The Economist. War damage of 2% is assumed each year over the periods 1914-17 and 1942-1945 following A. Maddison, 1995, *op cit.* Germany: W. Kirner, 1968, *Zeitreihen für das Anlagevermögen der Wirtschaftsbereiche in der Bundesrepublik Deutschland*, Deutsches Institut für Wirtschaftsforschung, Berlin: Duncker & Humboldt. The data are adjusted for war damage in the source. Non-residential buildings and structures 1850-1949. The following categories are added together: Land und Forstwirtschaft, Energiewirtschaft, Bergbau, Grundstoff- und Productiongüter-industrie, Investiergüterindustrie, Verbrauchgüterindustrie, Nahrungs- und Genussmittel-industrie, Industrie Kleinbetr. und Handwerk, Baugewerbe, Handel, Eisenbahnen, Schifffahrt, Ubringer Verkehr, Nachr. übermittlg, Kreditinstitutionen und Vers. gew., Wohnungsvermietung, Sonst. Dienstleist., Strassen und Bruken, Wasser strassen und Hafen, and Ubrige staatl. Bereiche. Machinery and equipment 1926-1949. The same categories are added together as for investment in non-residential buildings and structures. 1870-1925: Scaled investment in machinery and equipment for Denmark, using the average over the period 1926-1930 as scaling factor. Italy. Istituto Centrale di Statistica, 1976, *Statistiche Storiche Dell'Italia 1861-1975*. Residential building investment is included in investment in buildings. Only 10-year averages are available before 1945. The data are uniformly distributed within the 10-year intervals. Netherlands. 1800-1913: J-P. Smits, E. Horlings, and J. L. van Zanden, 2000, *Dutch GNP and its Components, 1800-1913*, Groningen, <http://www.eco.rug.nl/ggdc/PUB/dutchgnp.pdf>. The general investment deflator is used as deflator. 1913-60: Central Bureau voor de Statistiek, 2001, *Tweehondred Jaar Statistiek in Tijdreeksen, 1800-1999*, Centraal Bureau voor de Statistiek, Voorburg. 10% war damage is evenly spread out over the years 1943-1945. Norway. Statistisk Sentralbyrå, 1968, *Nasjonalregnskap*, Oslo. 1865-1930: The investment data are derived from capital stock and official depreciation rates using the following formulae for buildings and equipment, respectively: $I_t^{eq} = K_t^{eq} - K_{t-1}^{eq}(1 - 0.15)$ and $I_t^{st} = K_t^{st} - K_{t-1}^{st}(1 - 0.02)$. 1930-1949: The data are interpolated from 1940 to 1945 using the algorithm suggested by V. Gomez and A. Maravall, 1994, "Estimation Prediction and Interpolation for Nonstationary Series with the Kalman Filter," *Journal of the American Statistical Association*, 89, 611-624. The general investment price deflator is used to adjust the *pre*-1940 data, which are in 1938 prices, whereas the *post*-1945 data are in 1955 prices. Spain. A. Carreiras *et al.*, 1989, *Estadísticas Históricas De España*, Madrid: Fundación Banco Exterior. 1850-1960: The growth rate in total investment is used to backdate investment in structures and machinery, respectively. Sweden. 1861-1949: O. Krantz and C. A. Nilsson, 1975, *Swedish National Product 1861-1970*, C. W. K. Gleerup. Investment in buildings includes residential investment. Switzerland. Ritzmann-Blickenstorfer, 1996, *op cit.*. The growth rate in total investment is used to backdate the data from 1922. UK. A. Maddison, 1995, *op cit.* An annual 3.5% war damage is corrected for in the estimates during the 1943-45 period.

Economy-wide real GDP. The data are from OECD, *National Accounts*, after 1950. Before 1950: A. Maddison, 1995, *Monitoring the World Economy 1820-1992*, OECD, except for the following countries. Australia. B. Haig, 2001, "New Estimates of Australian GDP 1861-1948/49," *Australian Economic History Review*, 41, 1-34. From 1939 onwards, A. Maddison, 1995, *op cit.* Finland. R. Hjerpe, (1989, *op cit.* Italy. C. Bardini, A. Carreras, and P. Lains, 1995, "The National Accounts for Italy, Spain and Portugal," *Scandinavian Economic History Review* XLII, 115-146. Netherlands. Central Bureau voor de Statistiek, 2001, *op cit.* Norway. O. H. Grytten, 2004, "The Gross Domestic Product for Norway 1830-2003," in Chapter 6 in Ø Eitrheim, J. T. Klovland and J. F. Qvigstad (eds.) *Historical Monetary Statistics for Norway 1819-2003*, Norges Bank Occasional Papers No 35, Oslo, 241-288. Spain. C. Bardini *et al.*, 1995, *op cit.* Sweden. O. Johansson, 1967, *The Gross Domestic Product of Sweden and its Composition 1861-1955*, Stockholm: Almquist and Wiksell. Switzerland. Ritzmann-Blickenstorfer, 1996, *op cit.* C. H. Feinstein, 1976, *Statistical Tables of*

National Income, Expenditure and Output of the UK 1855-1965, Cambridge: Cambridge University Press.

Economy-wide nominal GDP. Real GDP multiplied by economy-wide GDP-deflators from the following sources. Canada. M. C. Urquhart, 1988, "Canadian Economic Growth 1870-1980," Queens University Discussion Paper No 734. USA. 1870-1929: N. S. Balke and R. J. Gordon, 1986, *The American Business Cycle: Continuity and Change*, Chicago: University of Chicago Press. 1929-1960: Survey of Current Business August 1998: "GDP and Other Major NIPA Series 1927-97". Japan. K. Ohkawa, M. Shinchara and L. Meissner, 1979, *Patterns of Japanese Economic Development: A Quantitative Appraisal*, New Haven: Yale University Press. Before 1885, CPI is used as deflator. Australia. W. Vamplew, 1987, *Australian Historical Statistics*, Broadway, N.S.W: Fairfax. Belgium. CPI is used as deflator. B. R. Mitchell, 1975, *European Historical Statistics 1750-1975*, London : Macmillan. Denmark. S. A. Hansen, 1976, *Økonomisk Vækst I Danmark*, Copenhagen: Akademisk Forlag. Finland. R. Hjerpe, 1989, *op cit*. France. P. Villa, 1993, *Une Analyse Macroéconomique De La France Au XX^e Siècle*, Paris: CNRS Editions, and M. Lévy-Leboyer and F. Bourguignon, 1985, *The French Economy in the Nineteenth Century*, Cambridge: Cambridge University Press. Germany. T. Liesner, 1989, *op cit* and interpolated using CPI over the periods 1914-1924 and 1939-1949. Italy. C. Bardini *et al.*, 1995, *op cit* . Netherlands. Central Bureau voor de Statistiek, 2001, *op cit*. Norway. O.H. Grytten, 2004, *op cit*. Spain. Carreiras *et al.*, 1989, *op cit*. Sweden. O. Johansson, 1967, *op cit*. Switzerland. 1913-49. Ritzmann-Blickenstorfer, 1996, *op cit*. Backdated to 1870 using consumer prices, B.R. Mitchell, 1975, *op cit*. UK. C. H. Feinstein, 1976, *op cit*.

Average annual hours worked per employee. 1950-2004. Groningen Growth and Development Centre and the Conference Board, Total Economy Database, January 2005, <http://www.ggd.net>. These data are predominantly based on OECD's database on annual hours worked. 1870-1950. C. Clark, 1957, *The Conditions of Economic Progress*, London: Macmillan, except when indicated. The algorithm suggested by V. Gomez and A. Maravall, 1994, *op. cit.*, is used to interpolate between the benchmark years as indicated for the individual countries. Canada. 1870, 1880, 1890, 1900, 1910, 1920, and 1926-1949. The USA. 1868, 1873, 1878, 1883, 1888, 1993, 1898, 1903, 1908, and 1913-1949. Japan. 1901, 1913, and 1919-1949. Hours worked in 1901 are used before 1901. Australia. 1891, 1901, and 1919-1949. Hours worked in 1901 are used before 1901. Belgium. 1870, 1895, 1913, and 1920-50. Denmark. 1870, and 1903-1949. Finland. 1913, and 1924-1949. The growth rate is assumed to follow the growth rate in Sweden before 1913. France. 1870, 1880, 1890, 1913, 1920-38, and 1947-50. Germany. 1860, 1877, 1883, 1890-1913, and 1925-1950. Italy. 1901-1949. Hours worked in 1901 are used before 1901. Netherlands. 1870-1913. J.P. Smits *et al* (2000) *op cit*. 1913-39. Bart van Ark and Herman de Jong, 1996, "Accounting for Economic Growth in the Netherlands since 1913," Research Memorandum GD-26. 1939-50. C. Clark ,1957, *op cit*. Norway. 1891, 1913, 1920-1939, and 1946-1949. Backward extrapolation using the algorithm that is suggested by V. Gomez and A. Maravall, 1994, *op. cit*. Spain. Follows Italy before 1950. Sweden. The data are available for all years except for the years 1940-1944, where weekly hours worked from ILO, *Yearbook* are used to interpolate. Switzerland. 1890, 1895, 1899, 1924-50. The UK. The data are available for all years.

Total employment. Includes all economically active, with full-time equivalents. 1950-2004: OECD, *Labour Force Statistics*. 1870-1949. The following sources are used. The algorithm suggested by V. Gomez and A. Maravall, 1994, *op. cit.* is used to interpolate between the benchmark years as indicated for the individual countries. Canada. 1921-1959. F. H. Leacy *et al.*, 1983, *op. cit*. 1870, 1890, and 1913, and A. Maddison, 1991, *Dynamic Forces in Capitalist Development*, Oxford: Oxford University Press. The USA. 1900-1949. T. Liesner, 1989, *op cit*. 1870, 1890, and 1893: A. Maddison, 1991, *op. cit*. Japan. K. Ohkawa, *et al.*, 1979, *op. cit*. Australia. 1901-1949. M. W. Butlin, 1977, *op. cit*. A. Maddison, 1991, *op. cit*. Belgium. 1927-35

and 1945-1949. van Meerteen, 2003, *op cit.* Backdated from 1927 using population of working age (15-64) assuming a constant labour force participation rate, Mitchell, 1975, *op cit.* Denmark. 1870-1949. Hansen, 1976, *op cit.* Finland. 1870-1959. R. Hjerpppe, 1989, *op. cit.* Germany. 1870-1872, 1874-1914, 1924-1940, and 1949. W. G. Hoffmann, F. Grumbach, and H. Hesse, 1965, *Das Wachstum der Deutschen Wirtschaft seit der mitte des 19. Jahrhunderts*, Springer-Verlag: Berlin. Italy. 1901-1949. Clark, 1957, *op. cit.* 1870, and 1990. Maddison, 1991, *op. cit.* Netherlands. Central Bureau voor de Statistiek, 2001, *op cit.* Norway. 1903-1919. P. Flora, F. Kraus, and W. Phenning, 1987, *State, Economy, and Society in Western Europe 1815-1975*, London: Macmillan. 1920-1949. C. Clark, 1957, *op. cit.* 1870, and 1890. Maddison, 1991, *op. cit.* Spain. 1900-1949. Instituto De Estudios Fiscales, 1978, *Datos Basicos Para La Historia Financiera De Espana (1850-1975)*, Ministoio de Hacienda. Madrid. Backdated to 1870 using population of working age, B.R. Mitchell, 1975, *op cit.* Sweden. O. Johansson, 1967, *op cit.* Switzerland. 1924-1953, Clark, 1957, *op cit.* Backdated to 1870 using population of working age, Mitchell, 1975, *op cit.* UK. Clark, 1957, *op cit.*

Labour's share. Is calculated as the economy-wide compensation to employees plus imputed compensation to self-employed divided by nominal GDP. The imputed compensation to employees is computed as the number of self-employed multiplied by economy-wide compensation to employees divided by economy-wide employment. The output elasticities of inputs are computed from the average factor shares using data up to 2002. The following starting dates are used (in parentheses): Canada (1926), USA, (1899), Japan (1906), Australia (1870), Belgium (1950), Denmark (1900), Finland (1870), France (1920), Germany (1870), Italy (1950), Netherlands (1870), Norway (1930), Spain (1950), Sweden (1870), Switzerland (1950) and UK (1870). OECD *National Accounts* are used for the post-1950 data.

Compensation to employees. Canada. F.H. Leacy, 1983, *op cit.* USA. T. Liesner, 1989, *op cit.* Japan. K. Ohkawa *et al.*, 1979, *op cit.* Australia. Glenn Withers, Tony Endres and Len Perry, 1985, "Australian Historical Statistics: Labour Statistics," Australian National University, Source Papers in Economic History, No 7. Denmark. H.C. Johansen, 1985, *Dansk Historisk Statistik, 1814-1980*, København: Gyldendal. Finland. Table 12A, R. Hjerpppe, 1989, *op cit.* France. Table F.4, T. Liesner, 1989, *op cit.* Includes the non-agricultural sector. Germany. Table 122, W.G. Hoffmann *et al.*, 1965, *op cit.* Netherlands. Central Bureau voor de Statistiek, 2001, *op cit.* Norway. Statistisk Sentralbyraa, 1968, *op cit.* Sweden. Karl G. Jungenfelt, 1966, *Lonandelen och den Ekonomiska Utvecklingen*, Stockholm : Almqvist&Wiksell. UK. Table 1, C. H. Feinstein, 1976, *op cit.* Includes all sectors in the economy. Self-employment. 1950-2002. OECD *Labour Force Statistics*. Before 1950, the number of self-employed is assumed to be a constant fraction of total employment.

Self employment. 1950-2002. OECD *Labour Force Statistics*. Before 1950 the number of self-employed is assumed to be a constant fraction of total employment.

Imports. B R Mitchell, 1975, *op cit.* B. R. Mitchell, 1983, *International Historical Statistics: Americas and Australasia*, London: Macmillan, and B. R Mitchell, 1982, *International Historical Statistics: Asia and Africa*, London: Macmillan. New Zealand. *New Zealand Statistical Year-book*. Denmark. H.C. Johansen, 1985, *op cit.*

Bilateral trade weights. The following SITC classifications are used: SITC Section 5, chemicals and related products, Section 7, machinery and transport equipment, and Section 8.7, professional and scientific instruments. The data are interpolated between the following years: 1930, 1938, 1949, 1960, 1985 and 2002, and extrapolated back from 1930. The post 1960 data are from OECD, *Trade in Commodities*. The 1938 and 1949 data are from UN Economic and Social Council, 1951, *A General Survey of the European Engineering Industry*, Industry and Materials Division. The 1930 data are total imports and are from B.R. Mitchell, 1975, 1982, 1983, *op cit.*

Land. After 1961 the data are from FAOSTAT database <http://apps.fao.org/faostat>. Before 1961 the data are proxied by arable land from B.R. Mitchell, 1975, 1982, 1983, *op cit.* except for the following countries. USA. Department of Commerce, 1975, *Historical Statistics of the United States: Colonial Times to 1970*, Bureau of the Census: Washington D. C. Denmark. H.C.Johansen, 1985, *op cit.* Sweden. Central Bureau of Statistics, 1959, *Historical Statistics of Sweden Vol II*, Stockholm. UK. B.R. Mitchell, 1988, *British Historical Statistics*, Cambridge: Cambridge University Press.

Population. A Maddison, 1982, *Phases of Capitalist Development*, Oxford: Oxford University Press. Updated using IMF, *International Financial Statistics*.

Tariffs. B.R. Mitchell (1975, 1982, 1983) *op cit.* Australia. Wray Vamplew, 1987, *Australian Historical Statistics*, New South Wales: Fairfax. Updated using OECD, *Revenue Statistics*, Paris.

Unemployment

The data are available back to 1870 for three countries, while the data are available from the beginning of the 20th century for most countries. The data are interpolated by using the predicted values from regressing the log of real per capita GDP on the a time-trend and time-dummies using pooled cross section and time-series analysis for all 16 countries over the period from 1870 to 2004. The real per capita GDP is from A. Maddison, 1995, *op cit.* Over the period from 1950/1960 to 2004 the data are from OECD, *Labour Force Statistics*, Paris. The following data sources are used for the individual countries where the underlined numbers in parenthesis are the starting year. Canada (1916). A. Maddison, 1964, *Economic Growth in the West. Comparative Experience in Europe and North America*. London: George Allen & Unwin LTD. USA (1890). 1890-1930, C. Romer, 1986, "Spurious Volatility in Historical Unemployment Data," *Journal of Political Economy*, 94, 1-37. 1931-39, M. R. Darby, 1976, "Three and a Half Million US Employees have been Mislead: Or, and Explanation of Unemployment," *Journal of Political Economy*, 84, 1-16. Japan (1930). W. Galenson and A. Zellner, 1957, *Measurement and Behaviour of Unemployment*, NBER, Princeton: Princeton University Press. Australia (1870). 1870-1920. G. Withers, T. Endres, and L. Perry, 1985, *op cit.* M. Keating, 1973, *Australian Workforce and Employment 1910-11 to 1960-1*, the Australian National University, Canberra. Belgium (1921). A. Maddison, 1964, *op cit.* Denmark (1903). P. J. Pedersen, 1977, "Langtidssammenhæng mellem Produktivitetsstigning og Beskæftigelsesgrad," *Nationaløkonomisk Tidsskrift*, 175-192. Finland (1920). A. Maddison, 1977, "Phases of Capitalist Development," *Banca Nazionale del Lavoro-Quarterly Review*, 121, 103-137. France (1895). W. Galenson and A. Zellner, 1957, *op cit.* Germany (1887). A. Maddison, 1964, *op cit.* Italy (1925). A. Maddison, 1964, *op cit.* Netherlands (1870). 1870-1913. Dutch GDP and its components, 1800-1913. 1913-1950. W. Galenson and A. Zellner, 1957, *op cit.* Norway (1904). B.R. Mitchell, 1975, *op cit.* 1918-39. O. H. Grytten, 1995, "The Scale of Norwegian Interwar Unemployment in International Perspective," *Scandinavian Economic History Review*, 226-250. Spain (1932). *Monthly Bulletin of Statistics*, League of Nations, Geneva. Sweden (1914). B.R. Mitchell, 1975, *op cit.* 1920-1938. O. H. Grytten, 1992, "Arbeidsledighetens Omfang i Mellomkrigstiden", *Historisk Tidsskrift*, 3. Switzerland (1926). B.R. Mitchell, 1975, *op cit.* and A. Maddison, 1964, *op cit.* UK (1870). C. H. Feinstein, 1976, *op cit.*

Population. A. Maddison, 1995, *op cit.* From 1970: Groningen Growth and Development Centre and The Conference Board, Total Economy Database, January 2005, <http://www.ggd.net>.

Consumer prices: B. R. Mitchell, 1983, *op cit* , B. R. Mitchell, 1975, *op cit*, and B. R. Mitchell, 1982, *op cit*.

Mining sector nominal value added. From 1950-2006 or 1960-2006, OECD, *National Accounts*, Vol II, Paris. Canada. 1870-1926. M. C. Urquhart, , 1986, "New Estimates of Gross National Product, Canada, 1870-1926: Some Implications for Canadian Development," in S. Engermann, and R. E. Gallman (eds?), *National Bureau of Economic Research, Studies in Income and Wealth 51: Long-Term Factors in American Economic Growth*, Chicago: University of Chicago, 9-94. 1926-1960. T. Liesner, 1989, *op cit* . USA. *Mineral Resources of the US and Minerals Year Book*, US Geographical Survey. Japan. K. Ohkawa *et al.*, 1979, *op cit*. Australia: Vamplew, 1987, *op cit*. Belgium. Production of coal and steel (B.R. Mitchell, 1975, *op cit*.) multiplied by coal and steel prices. The total value of coal and steel production is spliced with the mining sector value of production in 1960. Coal prices are estimated using the following sources: 1870-1879. Unweighted average of the US (*Historical Statistics, op cit*. E 123-134), the Netherlands (Arthur van Riel, *Constructing the nineteenth-century cost of living deflator (1800-1913)*), and Switzerland (Ritzmann-Blickenstorfer, 1996, *op cit.*, H.7). 1879-1913. Unweighted average of the US (*Historical Statistics, op cit*. E 123-134 and M 93-106), the Netherlands (Van Riel *op cit.*), and Switzerland (Ritzmann-Blickenstorfer, 1996, *op cit.*, H.7). 1913-1963. Unweighted average of the US (*Historical Statistics, op cit*. E 123-134 and M 93-106), and Switzerland (Ritzmann-Blickenstorfer, 1996, *op cit.*, H.7). Steel prices. *Historical Statistics of the United States: Colonial Times to 1970*, 1970, *op cit*. E 123-134. The coal and steel prices are first converted to USD and thereafter to Euro's (see below for exchange rate sources). Denmark. S.A. Hansen, 1976, *op cit*. Finland: R. Hjerpe, 1989, *op cit*. France. Following the method used for Belgium production of coal and iron (B.R. Mitchell, 1975, *op cit*.) multiplied by coal and iron prices. The sources of coal prices are discussed above. Iron prices are found as follows: 1900-1970. Unweighted average of US (*Historical Statistics of the United States*, 1970, *op. cit*. Table M 205-220), UK (B. R. Mitchell, 1988, *British Historical Statistics*, Cambridge: Cambridge University Press, Cleveland Pig Iron, Prices 20) and Canada (F. H. Leacy *et al.*, 1983, *Historical Statistics of Canada*, Statistics Canada: Ottawa). Germany. Following the method used for Belgium for the following commodities: Coal, oil, iron, copper, lead, and zinc. The production of these commodities is from B.R. Mitchell, 1975, *op cit*. See under Belgium for sources of coal and iron prices. The other prices are from the following sources: Copper. 1970-1900. Unweighted average of wholesale prices for copper in the US (*Historical Statistics*, 1970, *op. cit*), The Netherlands (Van Riel *op cit*), (<http://www.iisg.nl/hpw/brannex.php>) and Denmark (S.A. Hansen, 1976, *op cit.*) 1900-1960. Bureau of Mines and the U.S. Geological Survey (<http://minerals.usgs.gov/ds/2005/140/#data>). Lead. 1870-1900. W. H. Beveridge, 1939, *Prices and Wages in England from the Twelfth Century*, London: Longmans Green & Co, p 738. 1900-1950. Grilli, Enzo and Maw Cheng Yang, 1988, "Primary Commodity Prices, Manufactured Goods Prices, and the Terms of Trade in Developing Countries," *World Bank Economic Review*, 2, 1-47. Oil. Unweighted average of the US (*Historical Statistics op cit*. M 138-142), US (before 1945) (<http://www.eia.doe.gov/emeu/international/petroleu.html>) and World spot prices (after 1945) (Arabian light), the Netherlands (Van Riel *op cit*), Sweden (Jonas Ljungberg, 1990, *Priser och Marknadskrafter i Sverige 1885-1969*, Lund: Ekonomisk-Historiska Föreningen), and Switzerland (Ritzmann-Blickenstorfer, 1996, *op cit.*, H.7). Zinc. 1870-1900. Bureau of Mines and the U.S. Geological Survey *op cit*. 1900-2005. Grilli, Enzo and Maw Cheng Yang, 1988, *op cit*. Italy. G. Fua, 1965, *Notes on Italian Economic Growth 1861-1964*, Milano: Mvltta Pavcis. Netherlands. Based on the same method and the same commodities as Belgium. Norway. Based on the same method and the same commodities as Belgium. Spain. Following the method used for Belgium for the following commodities: Coal, iron, copper and lead. See under Germany for sources. Sweden. Rodney Edvinsson, 2005, *Growth, Accumulation, Crisis: With New Macroeconomic Data for Sweden 1800-2000*, Stockholm: Almqvist & Wiksell International.

Exchange rates. 1950-2005. *IFS*. Before 1950 the following sources are used for individual countries. Canada. Global Financial Data. Japan. Global financial data. Australia. W. Vamplew,

1987, *op cit.* Denmark. H.C. Johansen, 1985, *op cit.* J.T. Klovland, 2004, "Historical exchange rate data 1819-2003," Historical Monetary Statistics for Norway 1819-2003, Norges Bank Occasional Papers no. 35, Oslo, 2004, Norges Bank. Netherlands. 1870-1913: N. W. Poathumus, 1946, Inquiry into the History of Prices in Holland, Leiden: Amsterdam. 1913-1950. Central Bureau voor de Statistiek, 2001, *op cit.* Norway. J.T. Klovland, 2004, *op cit.* Sweden. J.T. Klovland, 2004, *op cit.* UK. J.T. Klovland, 2004, *op cit.*

Agricultural sector nominal value added. From 1950-2006 or 1960-2006, OECD, *National Accounts*, Vol II, Paris. Canada. 1870-1926. M.C. Urquhart, 1986, *op cit.* and T. Liesner, 1989, *op cit.* USA. Historical Statistics, 1970, *op cit.* Japan. Kazuski, Miyoehei and Meissner, 1979, "Patterns of Japanese economic development: a quantitative appraisal", London: Yale University Press. Australia. B. Haig, 2001, *op cit.* Denmark. S.A. Hansen, 1976, *op cit.* Finland. R. Hjerppe, 1989, *op cit.* France. P. Villa, 1993, *op cit.* Germany. W.J. Hoffmann *et al.*, 1965, *op cit.* Italy. Fua, 1965, *op cit.* Netherlands. Central Bureau voor de Statistiek, 2001, *op cit.* Norway. Statistisk Sentralbyrå, 1968, *op cit.* Spain. Instituto De Estudios Fiscales, 1978, *op cit.* Sweden. Johansson, 1967, *op cit.* UK. B.R. Mitchell, 1988, *op cit.* and C.H. Feinstein, 1976, *op cit.*

Educational attainment. Estimating historical levels of human capital is a momentous task. Most earlier census surveys do not contain educational attainment. In the countries for which educational attainment is reported the educational classification often varies substantially over time. Even recent census surveys in the OECD countries have changed their educational classifications significantly over time (de la Fuente and Domenech, 2006). Furthermore, census surveys were only undertaken approximately every ten years before WWII and only slightly more frequently in the post-WWII period. Thus, census surveys are not suitable for constructing estimates of human capital in a historical context.

An alternative to census surveys is the perpetual inventory method in which school enrolment data are accumulated while allowing for depreciation. The perpetual inventory method is used for example by Lau Jamison, and Louat (1991) and Nehru, Swanson, and Dubey (1995). The problem associated with the perpetual inventory method is that survival rates and immigration flows are difficult to adequately deal with (Pritchett, 2005). If emigration is ignored human capital will be underestimated in countries that have experienced large immigration waves, such as Australia, New Zealand, Canada and the US, and overestimated for the European countries that have experienced large emigration waves over the past 137 years, particularly Ireland. Furthermore, educational attainment will be upwardly biased when survival rates are not considered. This is particularly true during the 19th century when the life expectancy was just below 50 years of age at the end of the century compared to a little above 30 at the beginning (Galor, 2005).

To overcome the data problems associated with survival and emigration a modified perpetual method is used in this paper. The method is based on the gross enrolment rate (GER), where GER is defined as the fraction of the population in a certain age cohort that is enrolled at a certain educational level. The GER for primary, secondary and tertiary school is estimated for each age cohort. Educational attainment in one particular year is then estimated as the average of the educational attainment for each age cohort in the labour force. School enrolment data are available on primary (6-11 years of age), secondary (12-17 years of age) and tertiary (18-22 years of age) levels for the countries considered in this study back to the 19th century. For some countries the data are extrapolated backward to ensure that primary school enrolment is available from 1812. In 1870, for example, the oldest cohort in the labour force (64 years of age) did their first year of primary schooling in 1812, while the youngest cohort (15 years of age) did its first year of primary schooling in 1861.

The advantage of using GER is that the estimates of educational attainment are not biased by migration and by assumptions about survival rates that may not hold. The only data that are required in addition to school enrolment is population distributed by age groups so that the GER

rate can be transformed to educational attainment for all age groups in the labour force. Population data on age groups are generally available in 10 year intervals during the period from 1860 to 1940 from the census surveys. Annual data become available after circa 1940 depending on the country in question. The missing observations are interpolated based on the following method. The fraction of the population in each age cohort is geometrically interpolated between the years in which data are available and multiplied by the total population. Over the period from 1812 to the first Census survey the population for different age cohorts is extrapolated back by multiplying the total population by the fraction of population in each age cohort from the first Census survey. In the estimates it is implicitly assumed that the educational attainment among emigrants is the same as the achievement among the labour force in the country from which they emigrate and the country to which they immigrate.

Finally, the data are adjusted for the length of the school year and school attendance rates. Attendance rates are available for Canada, Australia, and the US over the period from circa 1850 up to the 1960s. The post-1960 attendance rates are set equal to attendance rates that prevailed in the mid 1960s since attendance rates have been stable from the 1940s onwards. Attendance rates for Sweden are used before 1850. The average of attendance rates for Canada, Australia and the US are used for all countries, which is not likely to be a strong assumption since attendance rates for these three countries moved quite closely. The estimates of the length of the school year in Sweden by Ljungberg and Nilsson (2005) are used for all countries since I was not able to find similar data for other countries.

It is assumed that the length of primary schooling is six years (6-11 years of age), secondary schooling is six years (12-17 years of age) and tertiary schooling is five years (18-22 years of age). The average years of tertiary education among the population of working age, for example, is computed using the following formula:

$$Ea_t^{Ter} = \frac{2}{5} \left[\frac{1}{10} GER_{j=20,t-1} + \frac{2}{10} GER_{j=20,t-2} + \frac{2}{10} GER_{j=20,t-3} + \frac{2}{10} GER_{j=20,t-4} + \frac{2}{10} GER_{j=20,t-5} + \frac{1}{10} GER_{j=20,t-6} \right] \\ + \sum_{j=20}^{60} \left[\frac{1}{25} GER_{t-j+14} + \frac{2}{25} GER_{t-j+15} + \frac{3}{25} GER_{t-j+16} + \frac{4}{25} GER_{t-j+17} + \frac{5}{25} GER_{t-j+18} + \frac{4}{25} GER_{t-j+19} \right. \\ \left. + \frac{3}{25} GER_{t-j+20} + \frac{2}{25} GER_{t-j+21} + \frac{1}{25} GER_{t-j+22} \right] \\ j = (20, 25, \dots, 60) \in 20 - 24, 25 - 29, \dots, 60 - 64, \\ t = 1870, 1871, \dots, 2006,$$

where GER_j is the gross enrolment rate in age cohort j , which is defined as the ratio of enrolled students and the population in age cohort j . Note that the fractions in the squared brackets sum to one. The weights $1/25$, $2/25$ etc. is the fraction of students in each age cohort that were enrolled in the periods $t-46$, $t-45$ etc., where the divisor of 25 equals the average length of the tertiary degree in years of 5 (a fifth of the degree is taken in one year) multiplied by the number of age groups contained in each age cohort (there are 5 age groups in each cohort). In 1870, for example, only the individuals at the age of 64 in the 60-64 age cohort could be enrolled as students in 1824, while both the individuals at the age of 64 and 63 were enrolled in 1925, and therefore multiplied by 2, etc. In 1828 all individuals in the 60-64 cohort, who did a tertiary degree, were enrolled as students and GER is, therefore, multiplied by 5. Considering the first squared bracket, in which the 20-24 age cohort is considered, only individuals of the ages of 23 and 24 that were enrolled as students, have a degree. Thus, the squared bracket needs to be multiplied by $2/5$ and GER is divided by 10, which is the number of years in the first cohort (20-24) multiplied by the two year groups that can potentially take a degree.

Data for population in various age groups are typically available every ten years before WWII and on an annual basis thereafter. The data are interpolated between the census dates for the years in which data are not available and scaled up so the sum of all cohorts sum to the mid-year population which is available on an annual basis for all years.

For some countries the data are extrapolated backward to ensure that primary school enrolment is available from 1812. In 1870, for example, the oldest cohort in the labour force (64 years of age) did their first year of primary schooling in 1812, while the youngest cohort (15 years of age) did its first year of primary schooling in 1861.

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